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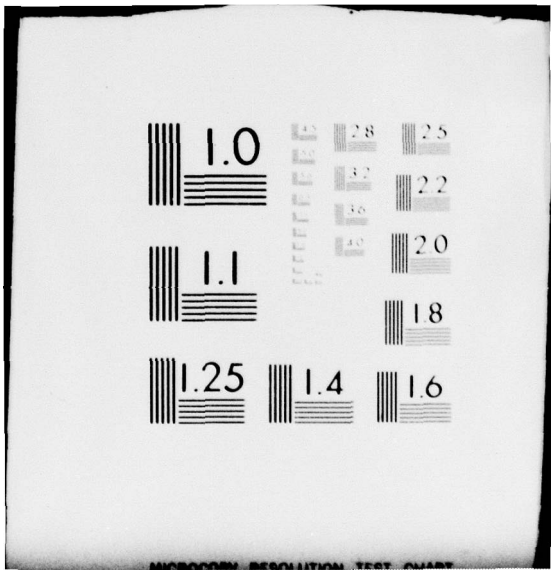
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Computer-based Education
Research Laboratory

University of Illinois Urbana Illinois

FINAL REPORT:

ANALYTICAL TEST THEORY MODEL FOR TIME AND SCORE

KIKUMI TATSUOKA

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

1. The object of this study was to find a way to utilize response-time data in the scoring procedure of achievement testing. The empirical study of adaptive diagnostic testing and a computerized instructional system revealed that the differences in type of information-processing skill developed by different instructional backgrounds affect the

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learning of further instructional materials to a great extent. This fact urges us to tap what information-processing strategy was used to respond to a given problem, not only considering individual differences in ability or achievement level, derived solely from the performance scores. It was seen that there were response patterns which yielded the same achievement level θ but the answers were obtained by two different approaches. If these individual differences in information-processing skills would not be detected on a diagnostic test, then a proactive inhibition effect will cause a serious learning deficiency, even for many good students, upon studying further instructional materials.

2. A model useful in identifying discriminating items that are sensitive to differences in instructional method was developed. It also is helpful in identifying an individuals' instructional background to a certain extent.

3. A method that estimates θ by regressing θ onto test-items was developed and compared with θ estimated by the maximum likelihood method. The new method provided as good θ as the traditionally established method did. This method is powerful when the number of subjects and test-items available are small. Also estimates are always obtainable, and moreover free from a choice of ordering test-items.

FINAL REPORT: ANALYTICAL TEST THEORY MODEL FOR TIME AND SCORE

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This research was sponsored by the Personnel and Training Research Programs, Psychological Science Division, Office of Naval Research, under Contract No. N00014-78-c-0159. Contract Authority Identification Number, NR 150-415.

Final Report July 1979

This is the final report of a year-long project which explored psychometric properties of response-time data and developed a model in which response-time was incorporated in scoring achievement tests. Validation of the model with real data has not yet been done, though the foundation of the model is based on theoretical and empirical research conducted by the principal investigator and Maurice Tatsuoka in the past few years. Many studies related to response-time have been done by experimental psychologists and cognitive scientists since the early years of this century. They first tried to discover an empirical relationship between intelligence and reaction time (we call it response-time in this study) in the perceptual domain but the results from various studies were so diverse that convincing relations were not obtained. Due to recent technical advances in computer science, computerized testing allows for more accurate measurement and control of time data. Thus it enabled cognitive psychologists to provide a large amount of information about the relations between response-time and various types of stimuli. Moreover, many psychological studies pertinent to an information-processing view of mental abilities have indicated the existence of a series of cognitive processes which differ among individuals. The intention of the model is to try to quantify individual differences in information-processing skills in terms of a latent response-time variable (analogous to the ability variable in latent trait theory) which affects the time taken by an examinee to answer each of a given set of test items. We did not attempt to give a precise psychological meaning for this construct beyond saying that it may be regarded as a pervasive trait of individuals to be slow or quick in solving items of a certain domain. The scope of this study was summarized

in Technical Report No. 3, A Model for Incorporating Response-time Data in Scoring Achievement Tests.

The other object of the project was to apply adaptive testing techniques to the interactive mode of actual instructions and testing with computer-managed routing systems. The computer-based education system at the University of Illinois (PLATO) has been widely utilized in teaching many subject areas for the past several years. Computerized adaptive tests of signed-numbers operations for a junior high school, and of matrix algebra for the multivariate statistics courses in the Departments of Psychology and Educational Psychology at the University of Illinois, were implemented along with computer-managed routing systems by which each student was sent to the instructional unit corresponding to the level of achievement at which she/he stopped in the initial tests. Conventional posttests were administered at the end of instruction.

The practical use of adaptive diagnostic testing together with computerized instruction raised interesting questions and problems. Some of the findings in the empirical study were summarized in Technical Report No. 2, The Danger of Relying Solely on Diagnostic Adaptive Testing when Prior and Subsequent Instructional Methods are Different. The dimensionality of performance scores on the posttest for signed-numbers was far from satisfying unidimensionality, while the scores on the very same test obtained from the previous study--in which adaptive diagnostic testing was not used and hence students studied a whole series of instructional lessons--showed a strong tendency toward unidimensionality. A cluster analysis of the examinees' response patterns led us to find a group of students whose performance on the test was significantly different from the

others. Their scores on items prior to the stopping level of the individual diagnostic test were higher those of most other students, while their scores on the subsequent items were as low as the poorest students' scores. We confirmed with their teachers that most of them were actually A-students. We also confirmed that the members of this group were taught signed-number addition operations by a teaching method different from that of subsequent instructional units, which teach subtraction operations. The procedures of information processing associated with these two instructional methods of performing arithmetic upon signed-numbers differ greatly. Fortunately, the response-time data that we observed gave us supplementary information which differentiates among individuals showing identical quality of performance. On the other hand, the traditional scoring procedure of latent trait theory, using performance scores, would not be capable of detecting the discrepancies associated with different information processes for arriving at the answer to a given item. The empirical study summarized in Technical Report No. 2 supports the notion of the new model introduced in Technical Report No. 3.

The first technical report, The Least Squares Estimation of Latent Trait Variables by a Hilbert Space Approach, describes the estimation method of the latent trait variable θ by regressing it on the predictor variables, the scores of all items used in an adaptive test. Latent trait theory has provided the only models that are applicable to assessing an individual student's ability level in an adaptive testing situation where each student takes a different set of items. The estimation of parameters of the latent trait theory models has been achieved iteratively by the maximum likelihood method. This method provides quite accurate values for

data generated by the Monte Carlo method, but it often fails to converge and cannot estimate the parameters for real data in which even a very few instances of certain kinds of unusual data are included; it also fails for either very high or very low θ values. This sensitivity is unfortunate, particularly when adaptive testing is used in practice, either as a diagnostic test or a posttest at the end of instruction. When diagnostic adaptive testing is used for routing each student to his/her most appropriate instructional unit in a series of lessons written on computer-based education systems, the problem of having nonconvergent θ values is severe. Some of our data showed about 10% of the students failing to obtain any fixed estimates of θ variable. The purpose of the study described in Technical Report No. 1 was to propose a new estimation method by which estimates of θ are always obtainable even for a small number of items. The results are compared with those obtained by the maximum likelihood method. It seems that the least squares multiple regression method is a useful alternative for providing estimation of θ when the other parameters, discriminating power and difficulty, are known.

ABSTRACTS OF RESEARCH REPORTS

TECHNICAL REPORT NO. 1

The Least-Squares Estimation of Latent Trait Variables by A Hilbert Space Approach

This paper searched for a new method for estimating a given latent trait variable by the least squares approach. The beta weights are obtained recursively with the help of Fourier series and expressed as functions of item parameters of response curves. The values of the latent

trait variable estimated by this method and by the maximum likelihood method were compared using real data. The results were very close, and yet the values of the latent trait variable estimated by the multiple regression method were always obtainable. The maximum likelihood method, on the other hand, often fails to converge.

TECHNICAL REPORT NO. 2

The Danger of Relying Solely On Diagnostic Adaptive Testing When Prior and Subsequent Instructional Methods are Different

A computerized diagnostic adaptive test for a series of pre-algebra signed-number lessons (which are also on the computer system) was programmed along with a computer-managed routing system by which each examinee was sent to the instructional unit corresponding to the level of skill at which she/he stopped in the initial test. Upon completion of the course a computerized conventional posttest was given to the examinees. The posttest scores were far from being unidimensional, while the pretest and posttest data obtained from a previous study, in which the pretest was a computerized conventional test and students were forced to go through all instructional units regardless of their achievement in the pretest, indicated a strong tendency to be unidimensional. The response patterns of the posttest in the present study showed a high error rate for the skills prior to stopping levels for one subgroup of examinees.

A cluster analysis was performed on the response patterns of the skills and four different groups were found. A discriminant analysis indicated significant differences among the four groups in response patterns of the skills in signed-number operations. After interviewing the teachers and several children, we came to the conclusion that it was the

difference between prior and current instructional methods that confused students and caused a mess in the posttest data. In other words, there was a proactive inhibition effect.

The scoring procedure of the adaptive testing did not consider individual differences in information-processing skills which were affected by the instructional method used in previous teaching. Thus, the students who were taught to perform the beginning part of a set of hierarchically ordered skills by instructional method A would very likely get confused in a lesson in which a different instructional method B was adopted. Consequently, quite a few peculiar response patterns were seen in the performance on the posttest. This fact cautions us that one should be careful not to rely solely on test results determined by performance scores on a diagnostic pretest when a computer-managed instructional system is to route each examinee to her/his initial level of instruction. It was suggested that we must somehow unravel what information-processing strategy was used and consider this knowledge simultaneously.

TECHNICAL REPORT NO. 3

A Model For Incorporating Response-Time Data In Scoring Achievement Tests

The differences in type of information-processing skill developed by different instructional backgrounds affect, negatively or positively, the learning of further advanced instructional materials. That is, if prior and subsequent instructional methods are different, a proactive inhibition effect produces low achievement scores on a posttest. This fact poses a serious problem for routing of students to an instructional level on the sole basis of performance on a diagnostic adaptive test. It is essential

that we somehow unravel what information-processing strategy was used and consider this knowledge simultaneously.

Fortunately, response-time often provides supplementary information which differentiates among individuals showing identical quality of performance. A model that reflects this kind of information, obtainable from response-time scores, is formulated in a similar manner to latent trait theory and is discussed. This model is useful in identifying discriminating items that are sensitive to differences in instructional method. It also is helpful in identifying an individual's instructional background to a certain extent.

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